MASTER OF SCIENCE
IN
OPERATIONS RESEARCH

APPLICATION OF A SYSTEM-BASED INVENTORY MODEL FOR MARINE CORPS REPAIRABLE PARTS
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A critical component of the Marine Corps' self-sustainment capability is its ability to procure and repair components for its ground equipment fleets. Secondary repairables consist of components that can be repaired, and for which repair is generally more economical and timely than purchase. The Marine Corps currently maintains spare repairable parts at seven principal locations, each operating independently of the other. There is excess inventory Service-wide because of the isolation of the inventories and because of mathematical flaws in the Marine Corps' sparing methodology. The Marine Corps is seeking to centralize the management of secondary repairables and is considering options that include centralizing responsibility and funding (while keeping the inventory model as it is) and changing the inventory model as well as the responsibility and funding. This thesis demonstrated that a centralized, "enterprise-wide" model of the inventory is superior to a decentralized one. Measures of comparison are total inventory cost and end-item availability. Stock levels calculated by both the current model and a commercial application called VMetric™-XL were evaluated. For a selected end-item, the current model produces stock levels totaling $25.9M in inventory and achieves 89.1% availability. For the same level of availability, Vmetric recommends stock levels totaling $2.9M, a stunning 89% reduction in cost. These results are explained and implications for Marine Corps logistics support are suggested.

ANALYSIS OF SELF-REPORTED SLEEP PATTERNS IN A SAMPLE OF US NAVY SUBMARINERS USING NONPARAMETRIC STATISTICS
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Fatigue contributes to increased accidents and mishaps and reductions in human performance. Inadequacies in the quality and quantity of sleep amongst U.S. Navy submariners can have detrimental effects on command and control functions, and can degrade overall human performance. The purpose of this study is to gain insight into the sleeping habits of U.S. Navy submariners. Using data supplied by the Naval Submarine Medical Research Laboratory, this study evaluates what a sub-sample of this population think about their sleep habits and will determine if there are differences in the reported amount of sleep between sailors in four different operational environments: 1) at sea, 2) in port, 3) on shore duty, and 4) on leave. The statistical analysis showed that there are discernable differences in the quality and quantity of sleep onboard U.S. submarines. There is a positive correlation between the amount of sleep obtained and the desired amount of sleep to function at every operational condition. Of the four operational conditions evaluated, the 'at sea' condition is the most different from all other conditions. Submariners reported getting less sleep while 'at sea' than other conditions. Finally, there is a positive correlation between the

amounts of sleep obtained (both total sleep and uninterrupted sleep) and the desired amounts of sleep needed to function in every operational condition leading to the inference that subjects who report needing more sleep do indeed get more sleep. When in the 'at sea' condition, this correlation was much weaker indicating that subjects have much less control over the amount of sleep they get when deployed.

OPTIMIZING THE NUMBER AND EMPLOYMENT OF COMBAT LOGISTICS FORCE SHUTTLE SHIPS, WITH A CASE STUDY OF THE T-AKE SHIP

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An optimization model that prescribes how Combat Logistics Force shuttle ships --- such as the new T-AKE 1 *Lewis & Clark* class auxiliary cargo-and-ammunition ship --- should be employed to sustain any number of deployed aircraft carrier (or other) battle groups (BGs) throughout a major theater war are presented. A variety of unclassified deterministic scenarios are developed involving between one and six BGs transiting worldwide to, e.g., the Baltic, the Arabian Sea, or Korea. Daily consumption of dry stores, ship fuel, aviation fuel, and ordnance is estimated. For each shuttle ship, it is assumed that the first consolidation visit to a BG can occur anywhere, but thereafter we track the shuttle ship back to a port to reload is tracked, and then back to rendezvous with some BG, and so forth. To precisely account for transit times, a global sea route model is presented that connects all resupply ports to waypoints, and distinguishes slow-speed passages through canals and restricted waterways, and legs that preclude BG consolidation visits. The objective is to deliver maximal quantities, and to avoid ever falling below BG safety stocks. The results tell how many shuttle ships are needed, and how to employ them.

AN ANALYSIS OF ROTARY WING OPERATIONS IN URBAN COMBAT USING THE JCATS COMBAT MODEL

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The trend of the world's population toward urban areas in the littoral region and increased likelihood of urban conflict has shifted the focus of the military to operations in the urban environment. There is interest within the DoD to evaluate the ability of U.S. forces to operate in the urban environment. In recent years, the Marine Corps has spent considerable time and effort conducting analysis on and development of urban warfare Tactics, Techniques and Procedures (TTPs). There is a need to refine and improve rotary wing operations in this setting.

This thesis modeled and conducted analysis on rotary wing (RW) operations in urban combat using the Joint Conflict and Tactical Simulation (JCATS) combat model. Focus was given to aircraft survivability to evaluate varying tactics and techniques to aid in development of Marine Corps RW TTPs. Thesis objectives were to evaluate rotary wing (RW) survivability in urban combat, determine the major factors impacting on RW survivability, give insight into the development of Marine Corps urban RW TTPs, and to evaluate JCATS as an urban combat modeling tool.

A fractional factorial design was used to vary tactical factors and evaluate their effects. Measures of Effectiveness (MOEs) for evaluation of these effects included Blue RW kills and Blue RW detections.

PLANNING U.S. PACIFIC COMMAND WARTIME FUEL DISTRIBUTION
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The Commander-in-Chief, U.S. Pacific Command (USCINCPAC) Joint Petroleum Office (JPO) plans wartime fuel distribution in the U.S. Pacific Command (USPACOM). The USCINCPAC JPO uses manual and spreadsheet based computational methods to assess fuel distribution infrastructures and Operational Plan (OPLAN) supportability. This thesis provides an optimization-based fuel distribution system consisting of linear programming models. Entitled Pacific Petroleum Distribution Model (PPDM), represents the USPACOM fuel distribution infrastructure and accounts for fifty Defense Fuel Support Points (DFSPs). Optimization models provide assessments of distribution capacity and present quantitative rationale to assist JPO in determining distribution requirements while planning and validating wartime fuel support. A series of analyses on notional data demonstrate PPDM's ability to conduct assessments. With OPLAN requirements of 94,000 MBBLs over the 120 day period, PPDM initially identifies significant shortages accumulated before 90 days. Subsequent PPDM analyses show alternatives to optimally schedule additional deliveries and reduce these shortages.

MODELING AND SIMULATION IN SUPPORT OF OPERATIONAL TEST AND EVALUATION FOR THE ADVANCED AMPHIBIOUS ASSAULT VEHICLE (AAAV)
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This thesis documents a simulation model developed to assist in the planning of Operational Test and Evaluation (OT&E) of the Marine Corps' Advanced Amphibious Assault Vehicle (AAAV). The model simulates a platoon of AAAVs in an amphibious assault, using Operational Maneuver From the Sea (OMFTS) techniques, supported by elements of a Marine Expeditionary Unit (MEU) aboard amphibious ships offshore. The emphasis of the model is on suitability issues, specifically operational availability, maintainability, and supportability. In particular the effect of logistical support for one AAAV on the ability of the platoon to complete a mission. The purpose of the simulation is to gain insight into important and highly sensitive factors that, when changed slightly, have large effects on the platoon of AAAV's ability to perform its mission.

The results of the model show that, the assumed form of the distribution of failure times for a single AAAV is the most important aspect of reliability test data. Simply calculating the mean time to failure (MTTF) from data and using an exponential model is inadequate. Even if an observed or estimated MTTF is within an acceptable requirement threshold level, if it is characterized by a high or even moderate number of infant failure times, then the platoon's ability to perform its mission is substantially impeded. Other factors that are of importance are the procedure by which a failed AAAV is rescued and repaired, and the average length of each repair.

ENHANCING REAL-TIME TOMAHAWK PREDESIGNATION TO DIAGNOSE CONFLICTS, PRESCRIBE IMPROVEMENTS, AND PLAN MULTIPLE STRIKES
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Tasking Tomahawk Land Attack Missiles (TLAM) to firing units is complex and time-consuming. This thesis shows how to help the Tomahawk Strike Coordinator (TSC) find efficient, logical and reproducible predesignations (allocations of TLAM tasks to firing units). Previous Naval Postgraduate School work has developed an optimal predesignation and a fast heuristic. However, there may be particularly constrained scenarios in which a complete allocation of tasks to firing units cannot be made. Based upon the cause for the unallocated tasks, the TSC must be able to diagnose and prescribe modifications to unassigned tasks efficiently and logically to arrive at the best allocation possible. This thesis embellishes the fast heuristic to diagnose why a task cannot be allocated and to provide the TSC with recommended modifications to tasks (e.g., change time of launch and/or eliminate redundant task parts). In addition, we improve the fast heuristic to allow sequential allocation of an arbitrary number of sets of tasks. These enhancements offer the TSC new capability to quickly and effectively plan strike warfare.

EVALUATION OF COMBAT SERVICE SUPPORT LOGISTICS CONCEPTS FOR SUPPLYING A USMC REGIMENTAL TASK FORCE
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One of the primary responsibilities of a Marine Corps Combat Service Support Element (CSSE) is to provide water, fuel, and ammunition requirements for the primary task forces and other Marine Expeditionary Force (MEF) elements. This thesis evaluates existing and proposed concepts on how to best use the CSSE resources of a Force Service Support Group to transport supplies to Regimental Combat Teams over constrained networks with time constraints. A model was developed that optimizes the use of resources, assets, and network routes. The model first solves a capacitated vehicle routing problem, where a set of customers has to be served by a fleet of vehicles within a certain time. The stochastic aspects of the problem are modeled through the use of a discrete event simulation that uses the results of the optimization model. The optimization model goes beyond the traditional routing problem by accounting for special features such as vehicle capacity for each commodity and cargo incompatibility (e.g. fuel and ammunition). The model includes both optimization of routes and simulation of stochastic elements. As a result, this thesis establishes a basis for future studies involved with modeling new concepts in Combat Service Support.

RELIABILITY AND LIFE DATA ANALYSIS FOR AN/AAS-44(V) FORWARD LOOKING INFRARED (FLIR) SYSTEM TO FORECAST H-60 OPERATIONAL AVAILABILITY
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The AN/AAS-44(V) Forward Looking Infrared (FLIR) System used on the Navy's H-60 Helicopter is taking on an increasing role in helicopter operations and is an important element in the Armed Helicopter design concept. Since its initial acquisition in 1997, the FLIR has been unable to achieve pre-acquisition

reliability requirements. Coupled with the high cost of FLIR components, the short times to failure of the FLIR impact Operational Availability (Ao) and cause funding for spares to exceed budgeted levels.

The ability to properly estimate system behavior provides the foundation to adequately fund the level of spares necessary to achieve a level of Ao and to assess the improved system reliability that would result from a system redesign. Two models are developed. The first model assumes the times between failures are independent identically distributed exponential for each unit with different means for individual units. The second model assumes that the times between failure are independent identically distributed and uses the empirical distribution. Both models are simulated. Simulation results are used to estimate the reliability improvement that a proposed system redesign will have. Simulation results also are used to estimate Ao as a function of the number of spares for a carrier battle group. Comparison of simulation results to the Navy's inventory model suggests that current allowance levels are not adequate to achieve mandated Ao goals.

ASSESSING THE UTILITY OF AN EVENT-STEP ASMD MODEL BY ANALYSIS OF SURFACE COMBATANT SHARED SELF-DEFENSE

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Anti-ship cruise missiles (ASCMs) are increasing in quantity, capability, and availability throughout the world, posing a significant threat to United States naval forces operating in littoral waters. The improving performance and growing availability of ASCMs makes a persuasive argument for the U.S. Navy to aggressively expand surface combatant defense systems, and perform periodic reviews of existing defensive tactics to ensure effective employment of new combat systems. To guide decision makers in both of these areas, simulation and modeling tools are frequently applied. This thesis assesses an event-step Anti-Ship Missile Defense (ASMD) model through the evaluation of two new hardkill weapon systems, the evolved Seasparrow Missile (ESSM) and an improved Rolling Airframe Missile (RAM). The performance of both systems is evaluated within the context of a single-ship and a multi-ship formation responding to ASCM attacks. The goal of this thesis is threefold, namely to assess the effectiveness of additional anti-ship missile defense systems and identify any tactical insights derived from the modeling results of the multi-ship formation. Following these employments of the model, an evaluation is made regarding the use of the ASMD model as a tool for the tactical commander.

DEVELOPING A PROCESS FOR THE DERIVATION OF THE PROBABILITY OF NEGATION FOR THEATER BALLISTIC MISSILE DEFENSE

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Currently there is some ambiguity about the probability of negation in the current literature of Theater Ballistic Missile Defense. The current literature specifies a probability of negation in defense of either a critical asset or a defended area. What needs to be determined is the probability of negation required per target to ensure that the point target or area is properly defended against a raid. This thesis develops a process to determine the probability of negation per target for Theater Ballistic Missile Defense. The aforementioned process led to the creation of a simple but useful tool implemented in Microsoft Excel. The tool allows for a variety of inputs to include multiple layers, varying levels of confidence, varying probabilities of engagement support, and a variable number of shots per salvo per layer. It is available at http://web.nps.navy.mil/~buttrey/Software.

ANALYSIS, DESIGN, IMPLEMENTATION AND EVALUATION OF GRAPHICAL DESIGN TOOL TO DEVELOP DISCRETE EVENT SIMULATION MODELS USING EVENT GRAPHS AND SIMKIT

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Discrete Event Simulation (DES) is one of the most widely used methodologies for Operations Research (OR) modeling and analysis. However, designing and implementing DES can be a time-consuming and error-prone task. This thesis designed, implemented and evaluated a tool, the Event Graph Graphical Design Tool (EGGDT), to help OR analysts in the design, implementation, and maintenance of DES reducing the development and debugging times.

The Unified Modeling Language was used to document the development of the EGGDT, which was programmed in Java using J2D and Swing. Human Factors techniques were employed to help in the design process and to evaluate the final prototype of the EGGDT.

During the design process, two formative experiments were performed to evaluate the Graphical User Interface design decisions. A final summative experiment was done to test if the potential users consider the tool a useful means to develop OR simulations. Participants of the experiments agreed that tools like the EGGDT are an essential instrument when developing simulations.

REDUCING NON-MONOTONICITIES IN COMBAT MODELS

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Non-monotonic behavior in combat models is an important topic to those using the output of such models as a basis for decision making. These decisions can be complicated by non-monotonic behavior in the combat models. This paper examines the Dewar model which exhibits non-monotonic behavior caused by the chaos inherent in its structure. Previous papers have examined only small subsets of this 18 dimensional combat model. The combinatorial possibilities of main effects and interactions among the 18 dimensions are too great to examine en masse. Consequently, there are three goals. First, systematically explore the Dewar model for additional non-monotonic behavior. Second, determine the effect of stochastic modeling on the non-monotonic behavior of the Dewar model response surface. Third, develop a method for measuring non-monotonicity in the response surface generated by the model. Latin Hypercube Sampling discovers non-monotonicity across broad regions of the model's phase space, and in multiple measures of effectiveness. Stochastic perturbation of model parameters has a dramatic effect on the non-monotonicity of the response surface. Stochastic perturbation can both reduce and exacerbate the non-monotonic behavior of the response surface. If done properly, stochastic modeling can significantly improve the interpretability of the response surface.

SCHEDULING THE RECRUITING AND MOS TRAINING OF ENLISTED MARINES

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Non-infantry enlisted Marines progress through Recruit Training, basic infantry training at Marine Combat Training (MCT), and Military Occupational Specialty (MOS) training before finally reporting to their first

unit for duty. These Marines are the focus of this thesis. In fiscal year 1998, new recruits spent over 2,700 Marine-years (wait time) in an unproductive status while waiting on their next training schools to convene. Marine Corps manpower planners believe this level of wait time is unacceptable. This thesis develops two integer linear programs to plan recruiting and MOS school seat scheduling with the primary objective to minimize the time non-infantry enlisted Marines wait for MOS training. The first model, the Long-term Recruiting and MOS School Scheduler (LRAMS) plans both recruiting and MOS training to help MOS training schools' develop their training schedules two years prior to execution. The second model, the Short-term Adjusted Recruiting Model (STAR) is used after the MOS training school schedules are published to develop a coordinated recruiting schedule. Results indicate that wait time can be reduced significantly. For fiscal year 2001, LRAMS results provide a wait time of only 160 Marine-years.

AN IMPROVED HEURISTIC FOR TOMAHAWK LAND-ATTACK PREDESIGNATION, ENHANCED TO ACCOMMODATE MANUAL PLANNING, AND VALIDATED WITH FLEET EXERCISE DATA

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The Tomahawk Land-Attack Missile (TLAM) has become the weapon of choice for strategic and tactical land-attack warfare. Tomahawk provides long-range, reliable, unmanned land-attack capability with pinpoint accuracy. Strike planning is the process by which Tomahawks are assigned to firing units for target prosecution. Currently, the Tomahawk Strike Coordinator (TSC) performs strike planning by hand. In order to improve strike planning, a fast heuristic has been developed to allocate TLAM tasks—the target to be attacked and the time period in which the missile must be fired—to firing units in multiple battle groups and launch areas over successive time periods. Until now, the heuristic with just 12 simulated scenarios was tested. To determine the heuristic's performance vis-à-vis current manual strike planning, heuristic solutions to TSC allocations from two U.S. Third Fleet exercises—TEXAS THUNDER 00-6 and RIMPAC 00-3 are compared. The heuristic produces a more efficient allocation than the TSC for every one of 13 exercise salvos. The heuristic to accommodate manual planning is augmented, with two computer-assisted alternatives - task-to-firing unit and firing unit-to-task - that help the TSC discover and address subtle details that influence mission success, and apply expert human judgment regarding practical considerations.